

What is claimed:

1 1. A method of measuring the performance of a
2 centrifugal pump for transferring fluid within a fluid
3 system, the method comprising the steps of:

4 determining a value of speed input to the
5 centrifugal pump;

6 determining a value of pump flow rate; and
7 using the value of speed input and the value of
8 pump flow rate to calculate one or more values
9 representing the performance of the centrifugal pump,

10 wherein the values of speed input and pump flow
11 rate are derived using measured or calculated values
12 without requiring down hole sensors.

1 2. The method of claim 1, wherein the values
2 representing the performance of the centrifugal pump
3 are values for one or more parameters selected from
4 the group consisting of pump minimum required suction
5 head pressure, pump head pressure, pump head pressure
6 at rated speed, pump mechanical input power limit, and
7 pump efficiency.

1 3. The method of claim 1 wherein the centrifugal
2 pump is coupled to an electric motor and the step of
3 determining the speed input to the centrifugal pump
4 comprises the steps of:

5 measuring values of electrical voltages applied
6 to the motor and currents drawn by the motor; and
7 using the measured values of electrical voltages
8 applied to the motor and currents drawn by the motor
9 to calculate a value for the motor speed.

1 4. The method of claim 3, wherein the values
2 representing the performance of the centrifugal pump
3 are values for one or more parameters selected from

4 the group consisting of pump minimum required suction
5 head pressure, pump head pressure, pump head pressure
6 at rated speed, pump mechanical input power limit, and
7 pump efficiency.

1 5. The method of claim 1, further comprising the
2 steps of:

3 using at or above ground sensors to determine
4 measured centrifugal pump performance values for one
5 or more of the calculated centrifugal pump performance
6 values;

7 comparing the measured centrifugal pump
8 performance values determined by the sensors with the
9 corresponding calculated centrifugal pump performance
10 values; and

11 generating a fault sequence if the difference
12 between corresponding values exceeds an allowable
13 limit.

1 6. A method of measuring the performance of a
2 centrifugal pump for transferring fluid within a fluid
3 system, the method comprising the steps of:

4 determining a value of speed input to the
5 centrifugal pump;

6 determining a value of torque input to the
7 centrifugal pump; and

8 using the value of speed input and the value of
9 torque input to calculate one or more values
10 representing the performance of the centrifugal pump,

11 wherein the values of speed input and torque
12 input are determined using measured or calculated
13 values without requiring down hole sensors.

1 7. The method of claim 6, wherein the values
2 representing the performance of the centrifugal pump

3 are values for one or more parameters selected from
4 the group consisting of pump flow rate, pump minimum
5 required suction head pressure, pump head pressure,
6 pump head pressure at rated speed, pump mechanical
7 input power limit, and pump efficiency.

1 8. The method of claim 6 wherein the centrifugal
2 pump is coupled to an electric motor and the step of
3 determining the torque and speed inputs to the
4 centrifugal pump comprises the steps of:

5 measuring values of electrical voltages applied
6 to the motor and currents drawn by the motor; and

7 using the measured values of electrical voltages
8 applied to the motor and currents drawn by the motor
9 to calculate a value for at least one of the
10 parameters selected from the group consisting of motor
11 torque and the motor speed.

1 9. The method of claim 8, wherein the values
2 representing the performance of the centrifugal pump
3 are values for one or more parameters selected from
4 the group consisting of pump flow rate, pump minimum
5 required suction head pressure, pump head pressure,
6 pump head pressure at rated speed, pump mechanical
7 input power limit, and pump efficiency.

1 10. The method of claim 6, further comprising the
2 steps of:

3 using at or above ground sensors to determine
4 measured centrifugal pump performance values for one
5 or more of the calculated centrifugal pump performance
6 values;

7 comparing the measured centrifugal pump
8 performance values determined by the sensors with the

9 corresponding calculated centrifugal pump performance
10 values; and

11 generating a fault sequence if the difference
12 between corresponding values exceeds an allowable
13 limit.

1 11. A method of measuring the performance of a fluid
2 system wherein a centrifugal pump is used for
3 transferring fluid within said fluid system, the
4 method comprising the steps of:

5 determining a value of speed input to the
6 centrifugal pump;

7 determining a value of pump flow rate;

8 using the value of speed input and the value of
9 pump flow rate to calculate one or more values
10 representing the performance of the centrifugal pump;
11 and

12 using the values representing the performance of
13 the centrifugal pump to calculate values representing
14 the performance of the fluid system,

15 wherein the values of speed input and pump flow
16 rate are derived using measured or calculated values
17 without requiring down hole sensors.

1 12. The method of claim 11, wherein the values
2 representing the performance of the fluid system are
3 one or more values selected from the group consisting
4 of pump suction pressure, pump discharge pressure,
5 flow head loss and fluid level.

1 13. The method of claim 11 wherein the centrifugal
2 pump is coupled to an electric motor and the step of
3 determining the speed input to the centrifugal pump
4 comprises the steps of:

5 measuring values of electrical voltages applied
6 to the motor and currents drawn by the motor; and
7 using the measured values of electrical voltages
8 applied to the motor and currents drawn by the motor
9 to calculate a value for the motor speed.

1 14. The method of claim 13, wherein the values
2 representing the performance of the fluid system are
3 one or more values selected from the group consisting
4 of pump suction pressure, pump discharge pressure,
5 flow head loss and fluid level.

1 15. The method of claim 11, further comprising the
2 steps of:

3 using at or above ground sensors to determine
4 measured fluid system performance values for one or
5 more of the calculated fluid system performance
6 values;

7 comparing each measured fluid system performance
8 value with the corresponding calculated fluid system
9 performance value; and

10 generating a fault sequence if the difference
11 between corresponding values exceeds an allowable
12 limit.

1 16. A method of measuring the performance of a fluid
2 system wherein a centrifugal pump is used for
3 transferring fluid within said fluid system, the
4 method comprising the steps of:

5 determining a value of speed input to the
6 centrifugal pump;

7 determining a value of torque input to the
8 centrifugal pump;

9 using the value of speed input and the value of
10 torque input to calculate one or more values

11 representing the performance of the centrifugal pump;
12 and

13 using the values representing the performance of
14 the centrifugal pump to calculate values representing
15 the performance of the fluid system,

16 wherein the values of speed input and torque
17 input are determined using measured or calculated
18 values without requiring down hole sensors.

1 17. The method of claim 16, wherein the values
2 representing the performance of the fluid system are
3 one or more values selected from the group consisting
4 of pump suction pressure, pump discharge pressure,
5 flow head loss and fluid level.

1 18. The method of claim 16 wherein the centrifugal
2 pump is coupled to an electric motor and the step of
3 determining the torque and speed inputs to the
4 centrifugal pump comprises the steps of:

5 measuring values of electrical voltages applied
6 to the motor and currents drawn by the motor; and
7 using the measured values of electrical voltages
8 applied to the motor and currents drawn by the motor
9 to calculate a value for at least one of the
10 parameters selected from the group consisting of motor
11 torque and the motor speed.

1 19. The method of claim 18, wherein the values
2 representing the performance of the fluid system are
3 one or more values selected from the group consisting
4 of pump suction pressure, pump discharge pressure,
5 flow head loss and fluid level.

1 20. The method of claim 16, further comprising the
2 steps of:

3 using at or above ground sensors to determine
4 measured fluid system performance values for one or
5 more of the calculated fluid system performance
6 values;

7 comparing each measured fluid system performance
8 value with the corresponding calculated fluid system
9 performance value; and

10 generating a fault sequence if the difference
11 between corresponding values exceeds an allowable
12 limit.

1 21. A method of controlling a centrifugal pump for
2 transferring fluid within a fluid system, the method
3 comprising the steps of:

4 determining a value of speed input to the
5 centrifugal pump;

6 determining a value of pump flow rate;

7 using the value of speed input and the value of
8 pump flow rate to calculate one or more values
9 representing the performance of the centrifugal pump;

10 using the centrifugal pump performance values to
11 produce one or more command signals; and

12 using the command signals to control the speed of
13 the centrifugal pump,

14 wherein the values of speed input and pump flow
15 rate are determined using measured or calculated
16 values without requiring down hole sensors.

1 22. The method of claim 21, wherein the step of using
2 centrifugal pump performance values to produce command
3 signals comprises the steps of:

4 selecting a centrifugal pump performance
5 parameter to control;

6 determining a setpoint for the selected
7 centrifugal pump performance parameter;

8 calculating a control signal using the setpoint
9 value of the selected centrifugal pump performance
10 parameter; and

11 calculating the command signals from the control
12 signal.

1 23. The method of claim 22, wherein the selected
2 centrifugal pump performance parameter is the pump
3 flow rate and the step of using the command signals to
4 control the speed of the centrifugal pump includes
5 repetitively switching the speed of the centrifugal
6 pump between a set pump speed for a portion of a cycle
7 period and zero speed for the remainder of the cycle
8 period to achieve an average pump flow rate equal to
9 the setpoint value of the pump flow rate.

1 24. The method of claim 22, wherein the selected
2 centrifugal pump performance parameter is the pump
3 head pressure.

1 25. The method of claim 21 wherein the centrifugal
2 pump is coupled to an electric motor and the step of
3 determining the speed input to the centrifugal pump
4 comprises the steps of:

5 measuring values of electrical voltages applied
6 to the motor and currents drawn by the motor; and
7 using the measured values of electrical voltages
8 applied to the motor and currents drawn by the motor
9 to calculate a value for the motor speed.

1 26. The method of claim 25, wherein the step of using
2 centrifugal pump performance values to produce command
3 signals comprises the steps of:

4 selecting a centrifugal pump performance
5 parameter to control;

6 determining a setpoint for the selected
7 centrifugal pump performance parameter;
8 calculating a control signal using the setpoint
9 value of the selected centrifugal pump performance
10 parameter; and
11 calculating the command signals from the control
12 signal.

1 27. The method of claim 26, wherein the selected
2 centrifugal pump performance parameter is the pump
3 flow rate and the step of using the command signals to
4 control the speed of the centrifugal pump includes
5 repetitively switching the speed of the centrifugal
6 pump between a set pump speed for a portion of a cycle
7 period and zero speed for the remainder of the cycle
8 period to achieve an average pump flow rate equal to
9 the setpoint value of the pump flow rate.

1 28. The method of claim 26, wherein the selected
2 centrifugal pump performance parameter is the pump
3 head pressure.

1 29. The method of claim 21 wherein the values
2 representing the performance of the pump comprise
3 values representing pump mechanical input power limit
4 and pump mechanical input power, and the step of using
5 the command signals to control the speed of the
6 centrifugal pump comprises the steps of:

7 comparing the pump mechanical input power limit
8 and pump mechanical input power; and

9 reducing the speed of the centrifugal pump if the
10 value of pump mechanical input power is greater than
11 the pump mechanical input power limit.

1 30. A method of controlling a centrifugal pump for
2 transferring fluid within a fluid system, the method
3 comprising the steps of:

4 determining a value of speed input to the
5 centrifugal pump;

6 determining a value of torque input to the
7 centrifugal pump;

8 using the value of speed input and the value of
9 torque input to calculate one or more values
10 representing the performance of the centrifugal pump;

11 using the centrifugal pump performance values to
12 produce one or more command signals; and

13 using the command signals to control the speed of
14 the centrifugal pump,

15 wherein the values of speed input and torque
16 input are determined using measured or calculated
17 values without requiring down hole sensors.

1 31. The method of claim 30, wherein the step of using
2 centrifugal pump performance values to produce command
3 signals comprises the steps of:

4 selecting a centrifugal pump performance
5 parameter to control;

6 determining a setpoint for the selected
7 centrifugal pump performance parameter;

8 calculating a control signal using the setpoint
9 value of the selected centrifugal pump performance
10 parameter; and

11 calculating the command signals from the control
12 signal.

1 32. The method of claim 31, wherein the selected
2 centrifugal pump performance parameter is the pump
3 flow rate.

1 33. The method of claim 32, wherein the step of using
2 the command signals to control the speed of the
3 centrifugal pump includes repetitively switching the
4 speed of the centrifugal pump between a set pump speed
5 for a portion of a cycle period and zero speed for the
6 remainder of the cycle period to achieve an average
7 pump flow rate equal to the setpoint value of the pump
8 flow rate.

1 34. The method of claim 31, wherein the selected
2 centrifugal pump performance parameter is the pump
3 head pressure.

1 35. The method of claim 30 wherein the centrifugal
2 pump is coupled to an electric motor and the step of
3 determining the speed input and the torque input to
4 the centrifugal pump comprises the steps of:

5 measuring values of electrical voltages applied
6 to the motor and currents drawn by the motor; and
7 using the measured values of electrical voltages
8 applied to the motor and currents drawn by the motor
9 to calculate a value for at least one of the
10 parameters selected from the group consisting of motor
11 torque and the motor speed.

1 36. The method of claim 35, wherein the step of using
2 centrifugal pump performance values to produce command
3 signals comprises the steps of:

4 selecting a centrifugal pump performance
5 parameter to control;
6 determining a setpoint for the selected
7 centrifugal pump performance parameter;
8 calculating a control signal using the setpoint
9 value of the selected centrifugal pump performance
10 parameter; and

11 calculating the command signals from the control
12 signal.

1 37. The method of claim 36, wherein the selected
2 centrifugal pump performance parameter is the pump
3 flow rate.

1 38. The method of claim 37, wherein the step of using
2 the command signals to control the speed of the
3 centrifugal pump includes repetitively switching the
4 speed of the centrifugal pump between a set pump speed
5 for a portion of a cycle period and zero speed for the
6 remainder of the cycle period to achieve an average
7 pump flow rate equal to the setpoint value of the pump
8 flow rate.

1 39. The method of claim 36, wherein the selected
2 centrifugal pump performance parameter is the pump
3 head pressure.

1 40. The method of claim 30 wherein the values
2 representing the performance of the pump comprise
3 values representing pump mechanical input power limit
4 and pump mechanical input power, and the step of using
5 the command signals to control the speed of the
6 centrifugal pump comprises the steps of:

7 comparing the pump mechanical input power limit
8 and pump mechanical input power; and

9 reducing the speed of the centrifugal pump if the
10 value of pump mechanical input power is greater than
11 the pump mechanical input power limit.

1 41. A method of controlling the performance of a
2 fluid system wherein a centrifugal pump is used for
3 transferring fluid within said fluid system, the
4 method comprising the steps of:

5 determining values of torque and speed inputs to
6 the centrifugal pump;
7 using the values of torque and speed inputs to
8 calculate one or more values representing the
9 performance of the centrifugal pump;
10 using the values representing the performance of
11 the centrifugal pump to calculate values representing
12 the performance of the fluid system;
13 using the system performance values to produce
14 one or more command signals; and
15 using the command signals to control the speed of
16 the centrifugal pump,
17 wherein the values of torque and speed inputs are
18 determined using measured or calculated values without
19 requiring down hole sensors.

1 42. The method of claim 41, wherein the step of using
2 fluid system performance values to produce command
3 signals comprises the steps of:

4 selecting a fluid system performance parameter to
5 control;
6 determining a setpoint for the selected fluid
7 system performance parameter;
8 calculating a control signal using the setpoint
9 value of the selected fluid system performance
10 parameter; and
11 calculating the command signals from the control
12 signal.

1 43. The method of claim 42, wherein the selected
2 fluid system performance parameter to control is the
3 pump suction pressure.

1 44. The method of claim 43, further comprising the
2 step of deriving the setpoint value for pump suction
3 pressure from a fluid level command.

1 45. The method of claim 44, further comprising the
2 step of determining the fluid level command, said step
3 of determining the fluid level command comprising the
4 steps of:

5 defining a fluid system performance
6 characteristic to optimize;

7 varying the fluid level incrementally through a
8 range of values;

9 determining a value representing the fluid system
10 performance characteristic for each value of fluid
11 level;

12 determining for which value of fluid level the
13 value representing the fluid system performance
14 characteristic is optimized; and

15 setting the fluid level command at the level
16 which produces the optimized value.

1 46. The method of claim 45, wherein the step of
2 determining the fluid level command is automatically
3 repeated at predetermined times.

1 47. The method of claim 45, further comprising the
2 step of periodically determining the pump efficiency
3 and repeating the step of determining the fluid level
4 command when a decrease in pump efficiency relative to
5 prior determinations of pump efficiency is detected.

1 48. The method of claim 45, wherein the fluid system
2 is a gas well, further comprising the step of
3 periodically determining the gas production and
4 repeating the step of determining the fluid level

5 command when a decrease in gas production relative to
6 prior determinations of gas production is detected.

1 49. The method of claim 43, wherein the step of using
2 the command signals to control the speed of the
3 centrifugal pump includes repetitively performing the
4 method comprising the steps of:

5 operating the centrifugal pump at a set speed
6 until the pump suction pressure decreases to a value
7 less than or equal to a pump suction pressure lower
8 limit, said pump suction pressure lower limit equal to
9 the pump suction pressure setpoint minus a tolerance;
10 and

11 operating the centrifugal pump at zero speed
12 until the pump suction pressure increases to a value
13 greater than or equal to a pump suction pressure upper
14 limit, said pump suction pressure upper limit equal to
15 the pump suction pressure setpoint plus a tolerance.

1 50. The method of claim 41 wherein the centrifugal
2 pump is coupled to an electric motor and the step of
3 determining the torque and speed inputs to the
4 centrifugal pump comprises the steps of:

5 measuring values of electrical voltages applied
6 to the motor and currents drawn by the motor; and

7 using the measured values of electrical voltages
8 applied to the motor and currents drawn by the motor
9 to calculate values for at least one of the parameters
10 selected from the group consisting of motor torque and
11 motor speed.

1 51. The method of claim 50, wherein the step of using
2 fluid system performance values to produce command
3 signals comprises the steps of:

4 selecting a fluid system performance parameter to
5 control;
6 determining a setpoint for the selected fluid
7 system performance parameter;
8 calculating a control signal using the selected
9 fluid system performance parameter; and
10 calculating the command signals from the control
11 signal.

1 52. The method of claim 51, wherein the selected
2 fluid system performance parameter to control is the
3 pump suction pressure.

1 53. The method of claim 52, further comprising the
2 step of deriving the setpoint value for pump suction
3 pressure from a fluid level command.

1 54. The method of claim 53, further comprising the
2 step of determining the fluid level command, said step
3 of determining the fluid level command comprising the
4 steps of:

5 defining a fluid system performance
6 characteristic to optimize;
7 varying the fluid level incrementally through a
8 range of values;

9 determining a value representing the fluid system
10 performance characteristic for each value of fluid
11 level;

12 determining for which value of fluid level the
13 value representing the fluid system performance
14 characteristic is optimized; and

15 setting the fluid level command at the level
16 which produces the optimized value.

1 55. The method of claim 54, wherein the step of
2 determining the fluid level command is automatically
3 repeated at predetermined times.

1 56. The method of claim 54, further comprising the
2 step of periodically determining the pump efficiency
3 and repeating the step of determining the fluid level
4 command when a decrease in pump efficiency relative to
5 prior determinations of pump efficiency is detected.

1 57. The method of claim 54, wherein the system is a
2 gas well, further comprising the step of periodically
3 determining the gas production and repeating the step
4 of determining the fluid level command when a decrease
5 in gas production is detected.

1 58. The method of claim 52, wherein the step of using
2 the command signals to control the speed of the
3 centrifugal pump includes repetitively performing the
4 method comprising the steps of:

5 operating the centrifugal pump at a set speed
6 until the pump suction pressure decreases to a value
7 less than or equal to a pump suction pressure lower
8 limit, said pump suction pressure lower limit
9 calculated as the pump suction pressure setpoint minus
10 a tolerance; and

11 operating the centrifugal pump at zero speed
12 until the pump suction pressure increases to a value
13 greater than or equal to a pump suction pressure upper
14 limit, said pump suction pressure upper limit
15 calculated as the pump suction pressure setpoint plus
16 a tolerance.

1 59. A method of controlling the performance of a
2 fluid system wherein a centrifugal pump is used for

3 transferring fluid within said fluid system, the
4 method comprising the steps of:
5 determining a value of speed input to the
6 centrifugal pump;
7 determining a value of pump flow rate;
8 using the value of speed input and the value of
9 pump flow rate to calculate one or more values
10 representing the performance of the centrifugal pump;
11 using the values representing the performance of
12 the centrifugal pump to calculate values representing
13 the performance of the fluid system;
14 using the system performance values to produce
15 one or more command signals; and
16 using the command signals to control the speed of
17 the centrifugal pump,
18 wherein the values of speed input and pump flow
19 rate are determined using measured or calculated
20 values without requiring down hole sensors.

1 60. The method of claim 59, wherein the step of using
2 fluid system performance values to produce command
3 signals comprises the steps of:
4 selecting a fluid system performance parameter to
5 control;
6 determining a setpoint for the selected fluid
7 system performance parameter;
8 calculating a control signal using the setpoint
9 value of the selected fluid system performance
10 parameter; and
11 calculating the command signals from the control
12 signal.

1 61. The method of claim 60, wherein the selected
2 fluid system performance parameter to control is the
3 pump suction pressure.

1 62. The method of claim 61, further comprising the
2 step of deriving the setpoint value for pump suction
3 pressure from a fluid level command.

1 63. The method of claim 62, further comprising the
2 step of determining the fluid level command, said step
3 of determining the fluid level command comprising the
4 steps of:

5 defining a fluid system performance
6 characteristic to optimize;

7 varying the fluid level incrementally through a
8 range of values;

9 determining a value representing the fluid system
10 performance characteristic for each value of fluid
11 level;

12 determining for which value of fluid level the
13 value representing the fluid system performance
14 characteristic is optimized; and

15 setting the fluid level command at the level
16 which produces the optimized value.

1 64. The method of claim 63, wherein the step of
2 determining the fluid level command is automatically
3 repeated at predetermined times.

1 65. The method of claim 63, further comprising the
2 step of periodically determining the pump efficiency
3 and repeating the step of determining the fluid level
4 command when a decrease in pump efficiency relative to
5 prior determinations of pump efficiency is detected.

1 66. The method of claim 63, wherein the fluid system
2 is a gas well, further comprising the step of
3 periodically determining the gas production and
4 repeating the step of determining the fluid level

5 command when a decrease in gas production relative to
6 prior determinations of gas production is detected.

1 67. The method of claim 61, wherein the step of using
2 the command signals to control the speed of the
3 centrifugal pump includes repetitively performing the
4 method comprising the steps of:

5 operating the centrifugal pump at a set speed
6 until the pump suction pressure decreases to a value
7 less than or equal to a pump suction pressure lower
8 limit, said pump suction pressure lower limit
9 calculated as the pump suction pressure setpoint minus
10 a tolerance; and

11 operating the centrifugal pump at zero speed
12 until the pump suction pressure increases to a value
13 greater than or equal to a pump suction pressure upper
14 limit, said pump suction pressure upper limit
15 calculated as the pump suction pressure setpoint plus
16 a tolerance.

1 68. The method of claim 59 wherein the centrifugal
2 pump is coupled to an electric motor and the step of
3 determining the speed input to the centrifugal pump
4 comprises the steps of:

5 measuring values of electrical voltages applied
6 to the motor and currents drawn by the motor; and

7 using the measured values of electrical voltages
8 applied to the motor and currents drawn by the motor
9 to calculate a value for motor speed.

1 69. The method of claim 68, wherein the step of using
2 fluid system performance values to produce command
3 signals comprises the steps of:

4 selecting a fluid system performance parameter to
5 control;

6 determining a setpoint for the selected fluid
7 system performance parameter;
8 calculating a control signal using the selected
9 fluid system performance parameter; and
10 calculating the command signals from the control
11 signal.

1 70. The method of claim 69, wherein the selected
2 fluid system performance parameter to control is the
3 pump suction pressure.

1 71. The method of claim 70, further comprising the
2 step of deriving the setpoint value for pump suction
3 pressure from a fluid level command.

1 72. The method of claim 71, further comprising the
2 step of determining the fluid level command, said step
3 of determining the fluid level command comprising the
4 steps of:

5 defining a fluid system performance
6 characteristic to optimize;

7 varying the fluid level incrementally through a
8 range of values;

9 determining a value representing the fluid system
10 performance characteristic for each value of fluid
11 level;

12 determining for which value of fluid level the
13 value representing the fluid system performance
14 characteristic is optimized; and

15 setting the fluid level command at the level
16 which produces the optimized value.

1 73. The method of claim 72, wherein the step of
2 determining the fluid level command is automatically
3 repeated at predetermined times.

1 74. The method of claim 72, further comprising the
2 step of periodically determining the pump efficiency
3 and repeating the step of determining the fluid level
4 command when a decrease in pump efficiency relative to
5 prior determinations of pump efficiency is detected.

1 75. The method of claim 72, wherein the system is a
2 gas well, further comprising the step of periodically
3 determining the gas production and repeating the step
4 of determining the fluid level command when a decrease
5 in gas production is detected.

1 76. The method of claim 70, wherein the step of using
2 the command signals to control the speed of the
3 centrifugal pump includes repetitively performing the
4 method comprising the steps of:

5 operating the centrifugal pump at a set speed
6 until the pump suction pressure decreases to a value
7 less than or equal to a pump suction pressure lower
8 limit, said pump suction pressure lower limit
9 calculated as the pump suction pressure setpoint minus
10 a tolerance; and

11 operating the centrifugal pump at zero speed
12 until the pump suction pressure increases to a value
13 greater than or equal to a pump suction pressure upper
14 limit, said pump suction pressure upper limit
15 calculated as the pump suction pressure setpoint plus
16 a tolerance.

1 77. A method of controlling the performance of a
2 fluid system wherein at least first and second
3 centrifugal pumps are connected in parallel and are
4 used for transferring fluid within said fluid system,
5 the method comprising the steps of:

6 determining values of speed input to each of the
7 centrifugal pumps;
8 determining values pump flow rate of each of the
9 centrifugal pumps;
10 using the values of speed input and pump flow
11 rate to calculate the efficiency of each centrifugal
12 pump;
13 using efficiency and flow of each centrifugal
14 pump to calculate the speed for each centrifugal pump
15 which would result in the most efficient operation of
16 the fluid system;
17 using the calculated speed for each centrifugal
18 pump to produce command signals; and
19 using the command signals to control the speed of
20 each centrifugal pump.

1 78. The method of claim 77 wherein the first and
2 second centrifugal pumps are coupled to first and
3 second electric motors, respectively, and the step of
4 determining the speed input to each of the centrifugal
5 pumps coupled to an electric motor comprises the steps
6 of:

7 measuring values of electrical voltages applied
8 to the first and second motors and currents drawn by
9 the first and second motors; and

10 using the measured values of electrical voltages
11 applied to the first and second motors and currents
12 drawn by the first and second motors to calculate for
13 the first and second centrifugal pumps values for at
14 least one of the parameters selected from the group
15 consisting of motor torque and motor speed.

1 79. The method of claim 77, wherein the step of
2 determining the pump flow rate of each of the
3 centrifugal pumps comprises the steps of:

4 determining values of torque input to each of the
5 centrifugal pumps; and

6 using the values of torque inputs and speed
7 inputs to the first and second motors and currents
8 drawn by the first and second motors to calculate for
9 the first and second centrifugal pumps values for pump
10 flow rate.

1 80. A method of controlling the performance of a
2 fluid system wherein a centrifugal pump is used for
3 transferring fluid within said fluid system, the
4 method comprising the steps of:

5 selecting a fluid system performance parameter to
6 control;

7 determining a setpoint for the selected fluid
8 system performance parameter;

9 determining values representing the performance
10 of the centrifugal pump;

11 determining values representing the performance
12 of the fluid system;

13 using the pump performance values and fluid
14 system performance values to calculate a feedforward
15 signal by predicting a value of mechanical input to
16 the centrifugal pump when operating with the selected
17 centrifugal pump performance value at the setpoint
18 value;

19 using the feedforward signal to generate command
20 signals; and

21 using the command signals to control the speed of
22 the centrifugal pump.

1 81. The method of claim 80, wherein the selected
2 fluid system performance parameter to control is the
3 pump suction pressure.

1 82. The method of claim 81, further comprising the
2 step of deriving the setpoint value for pump suction
3 pressure from a fluid level command.

1 83. The method of claim 82, further comprising the
2 step of determining the fluid level command, said step
3 of determining the fluid level command comprising the
4 steps of:

5 defining a fluid system performance
6 characteristic to optimize;

7 varying the fluid level incrementally through a
8 range of values;

9 determining a value representing the fluid system
10 performance characteristic for each value of fluid
11 level;

12 determining for which value of fluid level the
13 value representing the fluid system performance
14 characteristic is optimized; and

15 setting the fluid level command at the level
16 which produces the optimized value.

1 84. The method of claim 83, wherein the step of
2 determining the fluid level command is automatically
3 repeated at predetermined times.

1 85. The method of claim 83, further comprising the
2 step of periodically determining the pump efficiency
3 and repeating the step of determining the fluid level
4 command when a decrease in pump efficiency relative to
5 prior determinations of pump efficiency is detected.

1 86. The method of claim 83, wherein the system is a
2 gas well, further comprising the step of periodically
3 determining the gas production and repeating the step

4 of determining the fluid level command when a decrease
5 in gas production is detected.

1 87. The method of claim 81, wherein the step of using
2 the command signals to control the speed of the
3 centrifugal pump includes repetitively performing the
4 method comprising the steps of:

5 operating the centrifugal pump at a set speed
6 until the pump suction pressure decreases to a value
7 less than or equal to a pump suction pressure lower
8 limit, said pump suction pressure lower limit
9 calculated as the pump suction pressure setpoint minus
10 a tolerance; and

11 operating the centrifugal pump at zero speed
12 until the pump suction pressure increases to a value
13 greater than or equal to a pump suction pressure upper
14 limit, said pump suction pressure upper limit
15 calculated as the pump suction pressure setpoint plus
16 a tolerance.

1 88. A method of controlling the performance of a
2 fluid system wherein a centrifugal pump is used for
3 transferring fluid within said fluid system, the
4 method comprising the steps of:

5 using a check valve to prevent back flow through
6 the pump; and

7 repetitively switching the speed of the
8 centrifugal pump between a set pump speed for a
9 portion of a cycle period and zero speed for the
10 remainder of the cycle period to achieve an average
11 pump flow rate equal to a desired value of pump flow
12 rate.

1 89. A pump control system for controlling a
2 centrifugal pump for transferring fluid within a
3 wellbore, the pump control system comprising:
4 a plurality of sensors located at or above ground
5 level;
6 means responsive to the sensors for determining
7 values of torque and speed input to the centrifugal
8 pump;
9 means for using the values of torque and speed
10 input to calculate one or more values representing the
11 performance of the centrifugal pump; and
12 means for using the centrifugal pump performance
13 values to produce one or more command signals for
14 controlling the speed of the centrifugal pump,
15 the values of torque and speed input being
16 derived using measured or calculated values without
17 requiring down hole sensors.

1 90. The pump control system of claim 89, wherein said
2 means using the centrifugal pump performance values to
3 produce command signals includes means for calculating
4 a feedback signal indicative of the difference between
5 a current value of a selected centrifugal pump
6 performance parameter and a setpoint value of the
7 selected centrifugal pump performance parameter, and
8 means for calculating the command signals from the
9 feedback signal.

1 91. The pump control system of claim 90, wherein the
2 selected centrifugal pump performance parameter is the
3 pump flow rate.

1 92. The pump control system of claim 90, wherein the
2 selected centrifugal pump performance parameter is the
3 pump head pressure.

1 93. The pump control system of claim 89, wherein said
2 means using the centrifugal pump performance values to
3 produce command signals includes means for calculating
4 a feedforward signal by predicting a value of
5 mechanical input to the centrifugal pump when
6 operating with the selected centrifugal pump
7 performance value at the setpoint value, and means for
8 calculating the command signals from the feedforward
9 signal.

1 94. The pump control system of claim 91, including
2 means for repetitively switching the speed of the
3 centrifugal pump between a set pump speed for a
4 portion of a cycle period and zero speed for the
5 remainder of the cycle period to achieve an average
6 pump flow rate equal to the setpoint value of the pump
7 flow rate.

1 95. A pump control system for controlling a
2 centrifugal pump for transferring fluid within a fluid
3 system, the pump control system comprising:
4 means for determining a value of speed input to
5 the centrifugal pump;
6 means for determining a value of pump flow rate
7 of the centrifugal pump;
8 means for using the values of pump flow rate and
9 speed input to calculate one or more values
10 representing the performance of the centrifugal pump;
11 and
12 means for using the centrifugal pump performance
13 values to produce one or more command signals for
14 controlling the speed of the centrifugal pump;
15 means for calculating a feedforward signal by
16 predicting a value of mechanical input to the

17 centrifugal pump when operating with the selected
18 centrifugal pump performance value at the setpoint
19 value, and means for calculating the command signals
20 from the feedforward signal.

1 96. The pump control system of claim 95, wherein said
2 means for using the centrifugal pump performance
3 values to produce command signals includes means for
4 calculating a feedback signal indicative of the
5 difference between a current value of a selected
6 centrifugal pump performance parameter and a setpoint
7 value of the selected centrifugal pump performance
8 parameter, and means for calculating the command
9 signals from the feedback signal.

1 97. The pump control system of claim 96, wherein the
2 selected centrifugal pump performance parameter is the
3 pump head pressure.

1 98. The pump control system of claim 95, wherein said
2 means for calculating a feedforward signal includes
3 means for periodically determining gas or oil
4 production and adjusting a fluid level command in
5 response to detection of a decrease in gas or oil.

1 99. The pump control system of claim 96, wherein the
2 selected centrifugal pump performance parameter is the
3 pump flow rate, including means for repetitively
4 switching the speed of the centrifugal pump between a
5 set pump speed for a portion of a cycle period and
6 zero speed for the remainder of the cycle period to
7 achieve an average pump flow rate equal to the
8 setpoint value of the pump flow rate.

1 100. A pump control system for controlling a
2 centrifugal pump for transferring fluid within a gas
3 or oil well, the pump control system comprising:
4 means to calculate one or more values
5 representing the performance of the centrifugal pump;
6 means for using the values representing the
7 performance of the centrifugal pump to calculate
8 values representing the performance of the well;
9 means for using at least one of the system
10 performance values to calculate a feedforward signal;
11 and
12 means responsive to at least one of the system
13 performance values and to the feedforward signal to
14 produce one or more command signals for controlling
15 the speed of the centrifugal pump.

1 101. The pump control system of claim 100, wherein
2 said means for using the performance values to produce
3 command signals includes means for calculating a
4 feedback signal indicative of the difference between a
5 current value of the selected performance parameter
6 and a setpoint value of the selected performance
7 parameter; and means for using the feedback signal to
8 calculate the command signals.

1 102. The pump control system of claim 100, wherein
2 said means for calculating the feedforward signal
3 includes means for predicting a value of mechanical
4 input to the centrifugal pump when operating with the
5 selected pump performance value at the setpoint value.

1 103. The pump control system of claim 101, wherein the
2 selected performance parameter is the pump suction
3 pressure.

1 104. The pump control system of claim 103, wherein
2 said means for using the performance values to produce
3 command signals includes means for calculating the
4 setpoint for pump suction pressure from a fluid level
5 command.

1 105. The pump control system of claim 104, wherein
2 said means for using the system performance values to
3 produce command signals includes means for
4 periodically determining gas or oil production and
5 adjusting fluid level command in response to detection
6 of a decrease in gas or oil production.

1 106. The pump control system of claim 103, wherein
2 said means for using the command signals to control
3 the speed of the centrifugal pump includes means for
4 operating the centrifugal pump at a set speed until
5 the pump suction pressure decreases to a value less
6 than or equal to a pump suction pressure lower limit
7 that is equal to the pump suction pressure setpoint
8 minus a tolerance; and means for operating the
9 centrifugal pump at zero speed until the pump suction
10 pressure increases to a value greater than or equal to
11 a pump suction pressure upper limit that is equal to
12 the pump suction pressure setpoint plus a tolerance.

1 107. A pump control system for controlling at least
2 first and second centrifugal pumps connected in
3 parallel for transferring fluid within a fluid system,
4 the pump control system comprising:

5 means to determine values for the efficiency and
6 flow of each centrifugal pump;

7 means for using the values of efficiency and flow
8 of each centrifugal pump to calculate a speed for each

9 centrifugal pump which would result in the most
10 efficient operation of the fluid system;
11 means for using the calculated speed for each
12 centrifugal pump to produce command signals; and
13 means for using the command signals to control
14 the speed of each centrifugal pump.

1 108. The pump control system of claim 107 wherein at
2 least one centrifugal pump is coupled to an electric
3 motor and the means for determining the efficiency and
4 flow rate of at least one centrifugal pump coupled to
5 an electric motor includes means for measuring the
6 electrical voltages applied to the motor and currents
7 drawn by the motor and means for using the measured
8 values of electrical voltages applied to the motor and
9 currents drawn by the motor to calculate at least one
10 of the values selected from the group consisting of
11 motor torque and motor speed.

1 109. A pump control system for controlling a
2 centrifugal pump for transferring fluid within a fluid
3 system, the pump control system comprising:
4 means for determining values representing the
5 performance of the centrifugal pump;
6 means for determining values representing the
7 performance of the fluid system;
8 means for calculating a feedforward signal by
9 predicting a value of mechanical input to the
10 centrifugal pump when operating with a selected
11 centrifugal pump performance value at a setpoint
12 value; and
13 means for calculating from the feedforward signal
14 one or more command signals for controlling the speed
15 of the centrifugal pump.

1 110. The pump control system of claim 109, wherein the
2 selected performance parameter is the pump suction
3 pressure.

1 111. The pump control system of claim 110, wherein
2 said means for calculating a feedforward signal
3 includes means for calculating the setpoint for pump
4 suction pressure from a fluid level command.

1 112. The pump control system of claim 111, wherein
2 said means for calculating a feedforward signal
3 includes means for periodically determining gas or oil
4 production and adjusting fluid level command in
5 response to detection of a decrease in gas or oil
6 production.

1 113. The pump control system of claim 110, wherein
2 said means for using the command signals to control
3 the speed of the centrifugal pump includes means for
4 operating the centrifugal pump at a set speed until
5 the pump suction pressure decreases to a value less
6 than or equal to a pump suction pressure lower limit
7 that is equal to the pump suction pressure setpoint
8 minus a tolerance; and means for operating the
9 centrifugal pump at zero speed until the pump suction
10 pressure increases to a value greater than or equal to
11 a pump suction pressure upper limit that is equal to
12 the pump suction pressure setpoint plus a tolerance.

1 114. A pump control system for controlling a
2 centrifugal pump for transferring fluid within a gas
3 or oil well, the pump control system comprising:
4 means for determining values representing the
5 performance of the centrifugal pump;

6 means for determining values representing the
7 performance of the well;

8 means for calculating a feedforward signal by
9 predicting a value of mechanical input to the
10 centrifugal pump when operating with a selected
11 centrifugal pump performance value at a setpoint
12 value; and

13 means for calculating from the feedforward signal
14 one or more command signals for controlling the speed
15 of the centrifugal pump.

1 115. The pump control system of claim 114, wherein the
2 selected performance parameter is the pump suction
3 pressure.

1 116. The pump control system of claim 115, wherein
2 said means for means for calculating a feedforward
3 signal includes means for calculating the setpoint for
4 pump suction pressure from a fluid level command.

1 117. The pump control system of claim 116, wherein
2 said means for means for calculating a feedforward
3 signal includes means for periodically determining gas
4 or oil production and adjusting fluid level command in
5 response to detection of a decrease in gas or oil
6 production.

1 118. The pump control system of claim 115, wherein
2 said means for using the command signals to control
3 the speed of the centrifugal pump includes means for
4 operating the centrifugal pump at a set speed until
5 the pump suction pressure decreases to a value less
6 than or equal to a pump suction pressure lower limit
7 that is equal to the pump suction pressure setpoint
8 minus a tolerance; and means for operating the
9 centrifugal pump at zero speed until the pump suction

10 pressure increases to a value greater than or equal to
11 a pump suction pressure upper limit that is equal to
12 the pump suction pressure setpoint plus a tolerance.